Hutnické listy č. 1/2016, roč. LXIX
ISSN 0018-8069

Optimisation of the Number of Maintenance Workers Based on the Monte Carlo Algorithm

Optimalizace počtu údržbářů založená na algoritmu Monte Carlo

Ing. Martin Lampa, Ph.D.[1]**; Ing. Jun Li, Ph.D.**[2]

[1] VŠB – Technical University of Ostrava, Faculty of Metallurgy and Materials Engineering, 17. listopadu 15/2172, Ostrava-Poruba, Czech Republic

[2] Hubei University of Technology, Wuchang District, Wuhan, Hubei Province, China

S rozvojem počítačů a softwarových produktů dochází i ke stále většímu uplatnění početních (numerických) metod v manažerském rozhodování i v průmyslových podnicích. Rozhodování je jednou z nejvýznamnějších manažerských aktivit, které manažeři každodenně využívají při výkonu své funkce. Význam pojmu manažerské rozhodování se nejvíce projevuje v tom, že kvalita a výsledky rozhodovacích procesů ovlivňují efektivnost, fungování a prosperitu průmyslových podniků. Informace hrají v rozhodovacích procesech klíčovou úlohu. Rozhodovací procesy se obvykle chápou jako procesy shromažďování a transformace vstupních dat do výstupních informací. Zásadní úlohu v procesech získávání dat, shromažďování dat a jejich přeměny v informace hraje manažer, jehož znalosti, zkušenosti a intuice jsou nebytné pro správné rozhodování. Obvykle časový tlak a omezenost jednotlivých zdrojů zabraňují pečlivému hledání všech dat, na jejichž základě manažer získá kvalitní informace pro rozhodování. Nekvalitní informace a tím i nekvalitní rozhodování mohou být jeden z důvodů podnikatelského neúspěchu. Jednou z velmi dobře uplatnitelného simulačního algoritmu řešení na počítači je metoda Monte Carlo. Aplikace algoritmu Monte Carlo spočívá v nalezení souvislosti mezi jednotlivými veličinami, které jsou řešením zkoumaného problému a charakteristikami náhodných procesů reprodukovatelných na počítačích. Cílem článku je ukázat použití simulačního algoritmu Monte Carlo na příkladu optimalizace počtu údržbářů dílny s 12 stroji stejného typu.

***Klíčová slova:** vědecké řízení; optimalizace; simulace; algoritmus Monte Carlo*

With the development of computers and software products, there is now greater use of quantitative methods in industrial enterprises when making managerial decisions. [6] One of the most applicable solutions to computer simulation algorithms is the Monte Carlo method. Application of the Monte Carlo algorithm lies in finding a relation between the individual variables that are the solutions to the problem and that represent the characteristics of random processes reproducible on computers. The aim of this article is to show the application of the Monte Carlo algorithm through an example of optimising the number of maintenance workers in a workshop with 12 machines of the same type.

***Key words:** management science; optimisation; simulation; Monte Carlo algorithm*

Over the last two decades, there have been great advances in computer technology and these advances have also affected managerial decision-making. Mathematical methods with the use of computer technologies have been increasingly used in most problems of managerial decision-making. [5] One of the most applicable methods of computer implementation is the Monte Carlo method. It is a static, stochastic method that uses random (pseudo-random) numbers in the course of the calculation. Its application will be shown using an example of optimising the number of maintenance workers in a workshop with 12 machines of the same type.

1. The task

The optimal number of maintenance workers for a workshop with 12 machines of the same type has to be determined. Statistically, it was found that, on average, over the course of one shift, two machines encounter one malfunction, 6 machines operate with 2 malfunctions and 4 machines with 3 malfunctions. The duration of each malfunction, as a random variable with normal probability distribution, lasts 30 minutes on average with a standard deviation of 10 minutes. 1 hour of downtime equals a loss of 600 CZK. The average hourly wage of a maintenance worker is 100 CZK. The optimal number of maintenance workers has to ensure minimal costs associated with repairing any defects (including wages, maintenance and losses from downtime).

2. Analysis of the solution

It is a simple task to determine the optimal dimension of the operating system (the number of maintenance workers) with two crucial variables that lead to its solution:

- Intensity of the requirements entering the operating system (malfunction rate of the machines during a shift), characterised by:
  - the number of failures during one shift *P*,
  - malfunction duration *x*,
  - the moment of the malfunction's occurrence *M*.
- Operational intensity (the number of maintenance workers that eliminate the malfunctions during a shift) *U*.

Extreme situations:

- Undersized (low) number of maintenance workers:
  - low wages of maintenance workers N_U,
  - high losses from downtime N_P.
- Oversized (high) number of maintenance workers:
  - high wages of maintenance workers N_U,
  - low loss from downtime N_P.

It is necessary to set a number of maintenance workers *U* so that the costs associated with eliminating malfunctions during one shift *N* ($N = N_U + N_P$) are minimal = $N_{\min}$.

3. Algorithm of the solution

The decisive variables for solving the given task are random. They take different values depending on the random influences of a number of factors. From a retrospective statistical analysis, it was found that the variable of malfunction duration "*x*" can be considered random and subject to the law of normal probability distribution (a larger number of factors that are not of great significance and not connected to each other, affect the "fluctuations" of this variable – starting with the quality of the maintenance worker's performance, material availability, means of implementing the maintenance work and ending with the management system of the workshop). For each real number, the distribution function of (normal) probability distribution assigns a chance that the random variable "*x*" takes a value that is less than this number (Fig. 1).

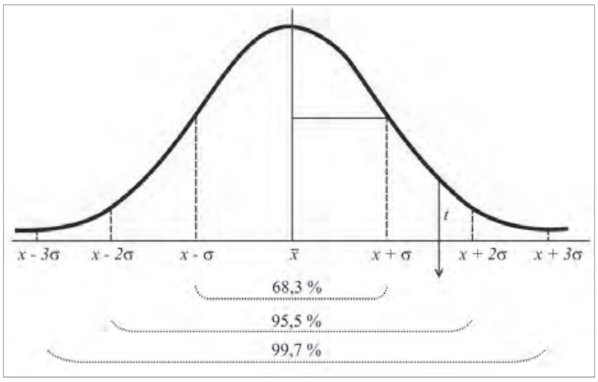

Fig. 1 Normal distribution of the function $x = \bar{x} + t{*}\sigma$
Obr. 1 Normální rozdělení funkce $x = \bar{x} + t{*}\sigma$

x – (random) value of the variable of malfunction duration (minutes),
$\bar{x}$ – mean value (average of values) of normal distribution (minutes),
σ – determinant deviation of normal distribution (minutes),
t – determinant variable;
$\bar{x}$ = 30 minutes
σ = 10 minutes

The given stochastic task can be solved through an artificial experiment based on the task's logical-mathematical model (see the analysis of the solution). [1] It is an artificial imitation of probabilistic situations and their assessment – imitation of the chance in accordance with the law according to which – as we assume – the chance acts. This methodology is referred to as simulation. Its essence, the result of its application, is a statistical estimate of the probability of the variant's course of real processes, and therefore, the optimal variant [3].

The Monte Carlo algorithm plays a significant role in simulation procedures [2]. The statistical estimation of probability occurs through artificial selections, using certain random mechanisms – usually random (pseudorandom) numbers.

Random numbers – a series (set) of statistically independent numbers (any number of the series does not depend on any of the previous or following numbers) [4].

The procedure of solving the task using the Monte Carlo algorithm

Simulation (prediction of the possible) duration of malfunctions *x* for 12 machines in the workshop, where for every:

- 2 machines – 1 malfunction
- 6 machines – 2 malfunctions
- 4 machines – 3 malfunctions

} statistically determined average during a shift

Through entering the random number generator - in this case the available table of random numbers, we generate five-digit numbers (for available five-digit values of the distribution function) that simulate the value of the distribution function and the corresponding value of the determinant variable *t* for the equation $x = \bar{x} + t{*}\sigma$, where $\bar{x}$ = 30 minutes, σ = 10 minutes.

a) Simulation (prediction of the possible) moment of occurrence of malfunctions *M* – in this case, again through entering the available table of random numbers, we generate three-digit numbers that simulate the moment of malfunction occurrence during a shift that lasts 0 – 480 minutes (Tab. 1).

b) Simulation of intervals of malfunction duration of individual machines during a shift is done based on the previous two steps (simulations). Their clear record can be found in the machine malfunction chart (Tab. 2).

$^{*}x = 30 + t{*}10$ (min)

Hutnické listy č. 1/2016, roč. LXIX
ISSN 0018-8069

Tab. 1 Simulation of the number of malfunctions during a shift
Tab. 1 Simulace počtu poruch během směny

The number of malfunctions during a shift	**Machine no.**	**Simulation (prediction of the possible) duration of malfunction *x***			**Simulation (prediction of the possible) interval of malfunction during a shift**		**Malfunction prior to the following shift**
		Simulated value of the distribution function	**t**	**Simulated durations of malfunction** $x = \bar{x} + t^*\sigma^*$	**Simulation of moment of malfunction occurrence *M***	**Simulation interval duration (*M* + *x*)**	
1	1	0.86649	1.11	41	345	386	
	2	0.16864	-0.96	20	342	362	
2	3	0.85645	1.06	41	105	146	
		0.42190	-0.20	28	36	64	
	4	0.80733	0.86	39	473	480	0 - 32
		0.01427	-2,19	8	424	432	
	5	0.94168	1.57	46	86	132	
		0.43059	-0.17	28	435	463	
	6	0.93731	1.53	45	142	187	
		0.20554	-0.82	22	234	256	
	7	0.73917	0.64	36	28	64	
		0.62711	0.32	33	162	195	
	8	0.72154	0.59	36	364	400	
		0.69191	0.50	35	145	180	
4	9	0.48653	-0.04	26	5	31	
		0.03872	-1.77	12	138	150	
		0.75660	0.70	37	169	206	
	10	0.73898	0.64	26	476	480	0 – 32
		0.42042	-0.20	28	345	373	
		0.11921	-1.18	18	213	231	
	11	0.17588	-0.93	21	236	257	
		0.51643	0.04	30	61	91	
		0.24635	-0.69	23	371	394	
	12	0.57576	0.19	32	241	273	
		0.64616	0.40	34	383	417	
		0.60538	0.27	33	457	480	0 - 10
Σ of time losses (downtime) of machines during the shift (minutes)			788				

Determining (predicting the possible) the overall malfunction rate - losses from downtime - for all machines in the workshop based on simulating the intervals of malfunction durations of the individual machines (from step 3) with the selected number of maintenance workers.

Minimum number of maintenance workers

$$U^{min} = \frac{\sum \textbf{of time losses (downtime) of machines during the shift} \ (\text{min})}{worker\ time\ fond\ (shift\ time)(min)}$$

$$U^{min} = \frac{788}{480} = 1.64 \text{ implying at least 2 maintenance workers per shift}$$

Maximum number of maintenance workers U^{max} is given by the maximum of malfunctioning machines at the same

U^{max} within the interval of 142 – 146 of the shift, there are 9 machines with a malfunction

U^{max} is a maximum of 6 maintenance workers

Tab. 2 Losses from downtime with individual numbers of maintenance workers
Tab. 2 Ztráty z prostojů při jednotlivých počtech údržbářů

Shift interval from - to (minu-tes)	The number of machines with a malfunc-tion	Losses from downtime (minutes) with the number of maintenance workers:							
		2	3	4	5	6	7	8	9
0-5	0	0	0	0	0	0	0	0	0
5-28	3	23	0	0	0	0	0	0	0
28-31	5	9	6	3	0	0	0	0	0
31-36	2	0	0	0	0	0	0	0	0
36-61	4	50	25	0	0	0	0	0	0
61-64	7	15	12	9	6	3	0	0	0
64-86	3	22	0	0	0	0	0	0	0
86-91	5	15	10	5	0	0	0	0	0
91-105	2	0	0	0	0	0	0	0	0
105-132	4	54	27	0	0	0	0	0	0
132-138	2	0	0	0	0	0	0	0	0
138-142	7	20	16	12	8	4	0	0	0
142-146	9	28	24	20	16	12	8	4	0
146-162	7	80	64	48	32	16	0	0	0
162-169	6	28	21	14	7	0	0	0	0
169-180	7	55	44	33	22	11	0	0	0
180-187	7	35	28	21	14	7	0	0	0
187-195	5	24	16	8	0	0	0	0	0
195-205	3	10	0	0	0	0	0	0	0
213-231	3	18	0	0	0	0	0	0	0
234-236	2	0	0	0	0	0	0	0	0
236-241	5	15	10	5	0	0	0	0	0
241-256	8	90	75	60	45	30	15	0	0
256-257	6	4	3	2	1	0	0	0	0
257-273	3	16	0	0	0	0	0	0	0
342-345	1	0	0	0	0	0	0	0	0
345-362	5	51	34	17	0	0	0	0	0
362-364	4	4	2	0	0	0	0	0	0
364-371	6	28	21	14	7	0	0	0	0
371-373	9	14	12	10	8	6	4	2	0
373-383	6	40	30	20	10	0	0	0	0
383-386	9	21	18	15	12	9	6	3	0
386-394	8	48	40	32	24	16	8	0	0
394-400	5	18	12	6	0	0	0	0	0
400-417	3	17	0	0	0	0	0	0	0
424-432	2	0	0	0	0	0	0	0	0
435-457	2	0	0	0	0	0	0	0	0
457-463	3	6	0	0	0	0	0	0	0
463-473	5	30	20	10	0	0	0	0	0
473-476	5	9	6	3	0	0	0	0	0
476-480	8	24	20	16	12	8	4	0	0
Σ		921	596	383	224	122	45	9	0

5. Evaluation of the simulation solution of the task

Determining the optimal number of maintenance workers U^{opt}

N = costs for wages of maintenance workers N_U (100 CZK/hour) + losses from downtime N_P (600 CZK/hour)

$$N = N_U + N_P \text{ (CZK)}$$

2 maintenance workers:

$N_U = 100 \times 2 \times 8 = 1\,600$ CZK

$N_P = 10 \times 921 = 9\,210$ CZK

$N = 1\,600 + 9\,210 =$ **10 810 CZK**

3 maintenance workers:

$N_U = 100 \times 3 \times 8 = 2\,400$ CZK

$N_P = 10 \times 596 = 5\,960$ CZK

$N = 2\,400 + 5\,960 =$ **8 360 CZK**

4 maintenance workers:

$N_U = 100 \times 4 \times 8 = 3\,200$ CZK

$N_P = 10 \times 383 = 3\,830$ CZK

$N = 3\,200 + 3\,830 =$ **7 030 CZK**

5 maintenance workers:

$N_U = 100 \times 5 \times 8 = 4\,000$ CZK

$N_P = 10 \times 224 = 2\,240$ CZK

$N = 4\,000 + 2\,240 =$ **6 240 CZK**

6 maintenance workers:

$N_U = 100 \times 6 \times 8 = 4\,800$ CZK

$N_P = 10 \times 122 = 1\,220$ CZK

$N = 4\,800 + 1\,220 =$ **6 020 CZK** $\rightarrow N_{min}$

7 maintenance workers:

$N_U = 100 \times 7 \times 8 = 5\,600$ CZK

$N_P = 10 \times 45 = 450$ CZK

$N = 5\,600 + 450 =$ **6 050 CZK**

8 maintenance workers:

$N_U = 100 \times 8 \times 8 = 6\,400$ CZK

$N_P = 10 \times 9 = 90$ CZK

$N = 6\,400 + 90 =$ **6 490 CZK**

9 maintenance workers:

$N_U = 100 \times 9 \times 8 = 7\,200$ CZK

$N_P = 10 \times 0 = 0$ CZK

$N = 7\,200 + 0 =$ **7 200 CZK**

Hutnické listy č. 1/2016, roč. LXIX
ISSN 0018-8069

Fig. 2 shows results of the choice of optimal variant in the number of maintenance workers, resp. minimal costs.

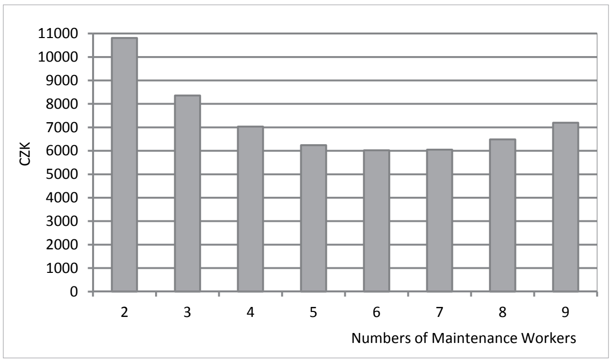

Fig. 2 The costs for various variants of numbers of maintenance workers
Obr. 2 Náklady pro různé varianty počtu údržbářů

Conclusions

From the viewpoint of minimising the total costs associated with repairing machine malfunctions and for the specified predictions of the number of malfunctions during a shift, employing 6 maintenance workers is the most optimal option. Employing the Monte Carlo algorithm is especially useful for repeated, routine solutions of standard problems, among which optimising the number of maintenance workers belongs, and when it is possible to incorporate the processed algorithm into a company's automated management system.

Acknowledgements

The work was supported by the specific university research of Ministry of Education, Youth and Sports of the Czech Republic No. SP2015/90.

Literature

[1] BESTA, P., SAMOLEJOVÁ, A., LENORT, R., ZAPLETAL, F. Innovative Application of Mathematical Methods in Evaluation of Ore Raw Materials for Production of Iron. *METALURGIJA*, 53 (2014) 1, 93–96.

[2] TURBAN, E., MEREDITH, J. R. *Fundamentals of management science*. USA: R. R. Donnelye & Sons, 1991, 1010 p.

[3] LAMPA, M., SAMOLEJOVÁ, A., KRAUSOVÁ, E. Optimal cutting of input material of metallurgical operations as a linear programming problems. In *METAL 2012* : 21st Anniversary International Conference on Metallurgy and Materials. Ostrava: TANGER, 2012, pp. 1355–1360. ISBN 978-80-87294-24-6.

[4] GROS I. *Kvantitativní metody v manažerském rozhodování*. Praha: GRADA Publishing: 2003. 432 s.

[5] LAMPA, M., SAMOLEJOVÁ, A., ROŽNOVSKÝ, L. Optimizing of Pallet Metallurgical Products Layout on Truck Loading Space. In *METAL 2011* : 20th Anniversary International Conference on Metallurgy and Materials, Ostrava: TANGER, 2011, pp. 1351-1361. ISBN 978-80-87294-24-6.

[6] SAMOLEJOVÁ, A., FELIKS, J., LENORT, R., BESTA, P. A Hybrid Decision Support System for Iron ore Supply. *METALURGIJA*, 51 (2012) 1, 91–93.

2016 bude dalším obtížným rokem pro globální ocelářský průmysl

Stahl Aktuell *07.01.2016*

Před globálním ocelářským průmyslem stojí další obtížný rok. „Není žádná maličkost, eliminovat přebytečné kapacity v rozsahu 600 milionů tun“ píšou analytici švýcarské banky UBS. A ačkoliv se v Asii konají seriozní pokusy o snížení přebytečných kapacit, jsou na jiných místech budovány nové kapacity. UBS ve světle těchto faktů počítá s krácením výroby v těch čínských ocelárnách, které se octly v obzvlášť hlubokých červených číslech. „Hodně bude záležet také na tom, jak silná budou mezinárodní antidumpingová opatření proti čínské oceli“. Pokud by v důsledku obchodních opatření klesly čínské exporty o 40 až 60 milionů tun, mohla by se situace na globálních trzích poněkud uvolnit a v důsledku toho by se mohly lehce zotavit i ceny. Analytici UBS počítají pro rok 2016 se vzestupem světové výroby oceli v rozsahu 2,1 %. Viditelná spotřeba by se měla vyvíjet v podobném směru. Vytížení výrobních kapacit ale zůstane i nadále nízké a bude se pohybovat kolem 70 %.

Železná ruda vystoupila na nejvyšší úroveň za poslední více než měsíc

Stahl Aktuell *07.01.2016*

Nejnovější zotavení čínských cen stavební oceli vedlo k tomu, že cena železné rudy dosáhla nejvyšší úrovně za více než jeden měsíc. Spotová cena stoupla na začátku týdne na 43,10 USD za tunu, Čínské zásoby stavební oceli klesly podle údajů šanghajského poradenského podniku Steel Home na 3,6 milionu tun, přičemž v březnu 2015 ležely ještě na úrovni kolem 8 milionů tun. Ve stejném časovém období stouply ceny futures stavební oceli, které platí jako měřítko pro ocel, stojící pod přísným dohledem, o zhruba 10 %.